02P 13417

63

(12) UK Patent Application (19) GB (11) 2 352 094 (13) A

(43) Date of A Publication 17.01.2001

(21) Application No 0026032.3

(22) Date of Filing 14.04.1997

Date Lodged 25.10.2000

(30) Priority Data
(31) 08631343 (32) 12.04.1996 (33) US

(62) Divided from Application No 9707524.6 under Section 15(4) of the Patents Act 1977

(71) Applicant(s)
Anorad Corporation
(Incorporated in USA - New York)
110 Oser Avenue, Hauppage, New York 11788, United States of America

(72) Inventor(s)
Anwar Chitayat

(74) Agent and/or Address for Service
K R Bryer & Co
7 Gay Street, BATH, BA1 2PH, United Kingdom

(51) INT CL[7]
H02K 9/00 9/19 41/035

(52) UK CL (Edition S)
H2A ARK1 ARK2 ARK3 ARK5 AR102 AR108 AR121 AR212 AR214R AR215R AR216R AR217S AR601R AR606R AR607R AR611

(56) Documents Cited
GB 1434151 A

(58) Field of Search
UK CL (Edition R) H2A ARD4 ARK3
INT CL[7] H02K 3/24 9/22 9/24 41/03
Online:WPI, CLAIMS, JAPIO

(54) Abstract Title
Linear motor with improved cooling

(57) A linear motor has an armature with at least one embedded coil (36). The armature is made up substantially non-magnetic material and includes a ceramic support member (70) having a recessed surface (71). The or each coil (36) is embedded in the recessed surface with epoxy resin. A heat sink in the form of a thermally conducting plate is in direct thermal contact with the ceramic support member to dissipate heat generated by the embedded coil or coils.

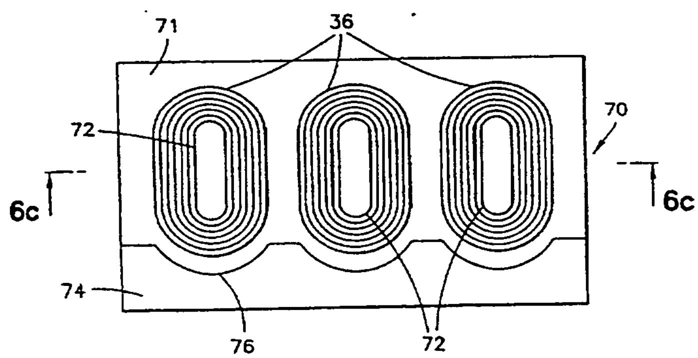

FIG.6a

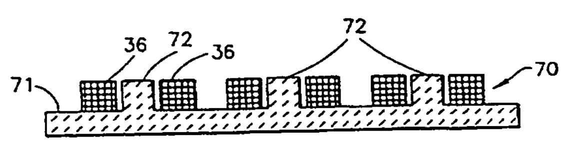

FIG.6c

GB 2 352 094 A

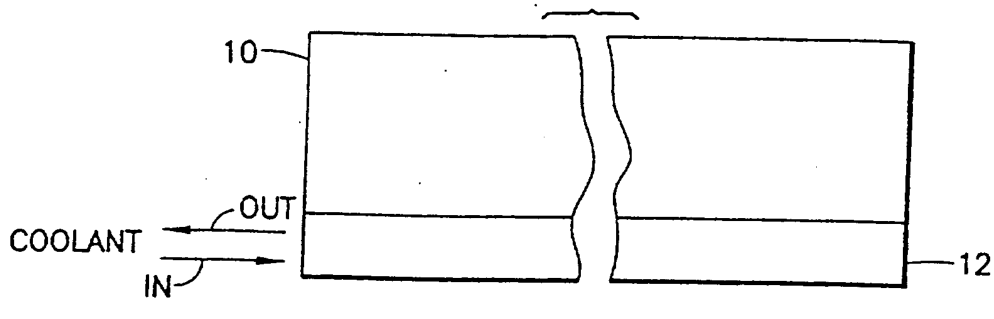

FIG. 1
PRIOR ART

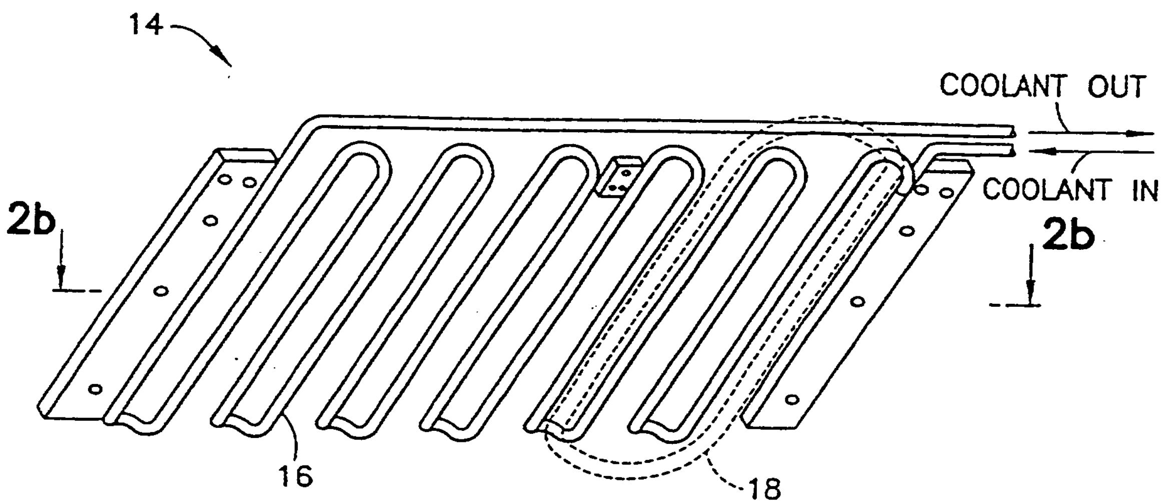

FIG. 2a
PRIOR ART

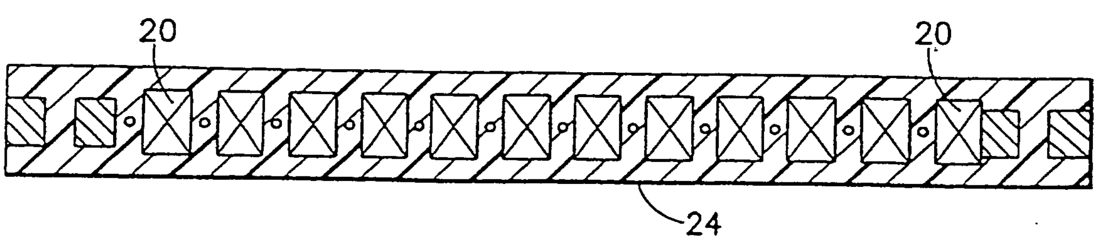

FIG. 2b
PRIOR ART

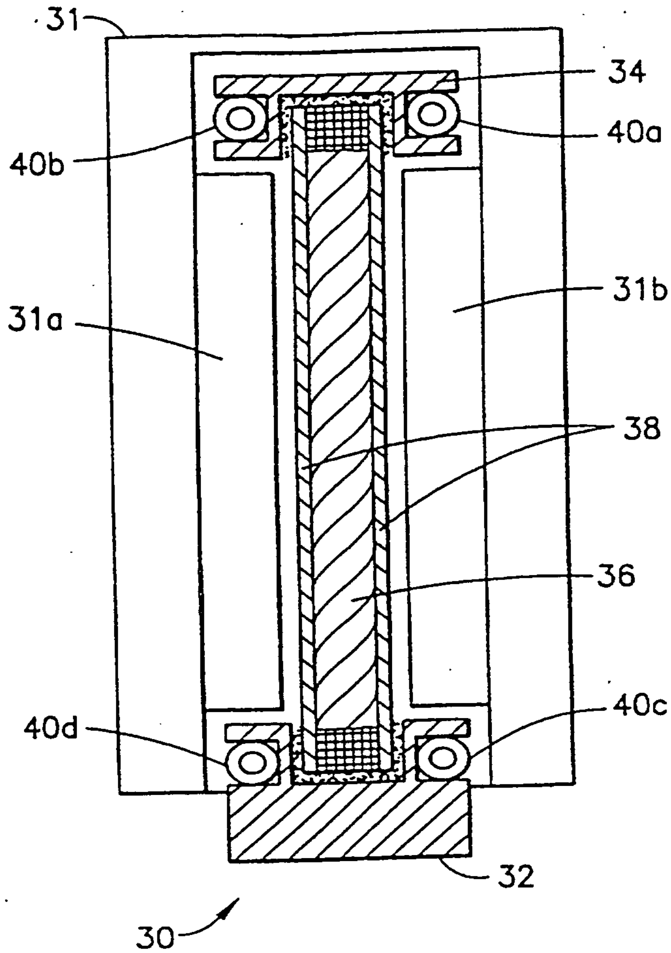

FIG.3a

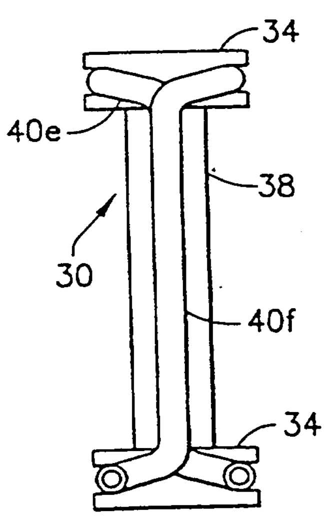

FIG.3b

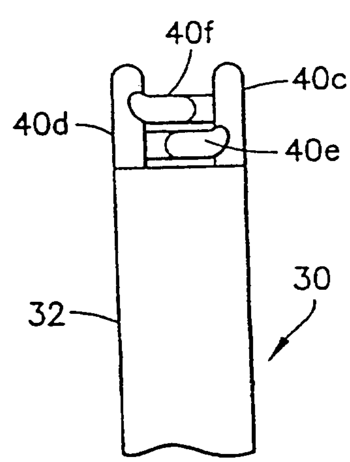

FIG.3c

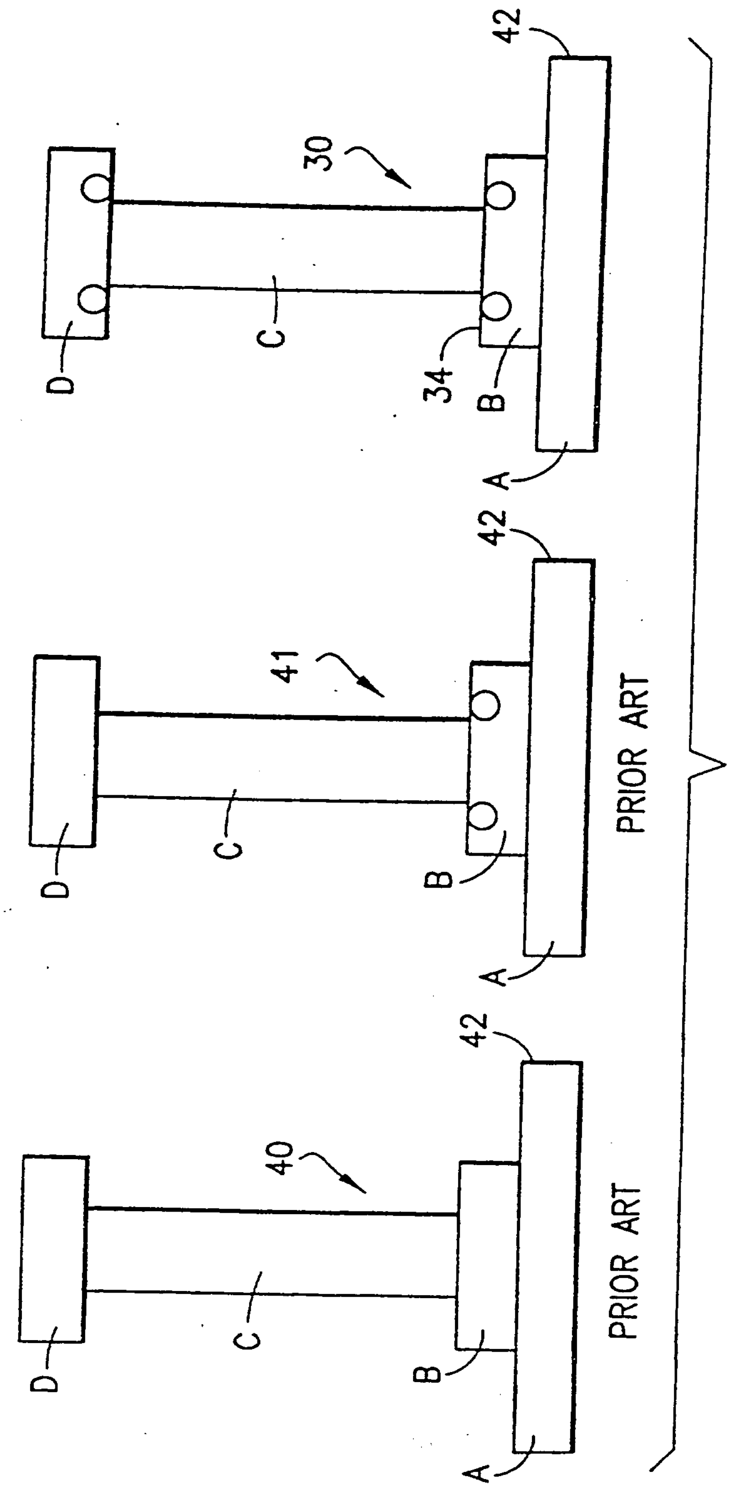

FIG.4

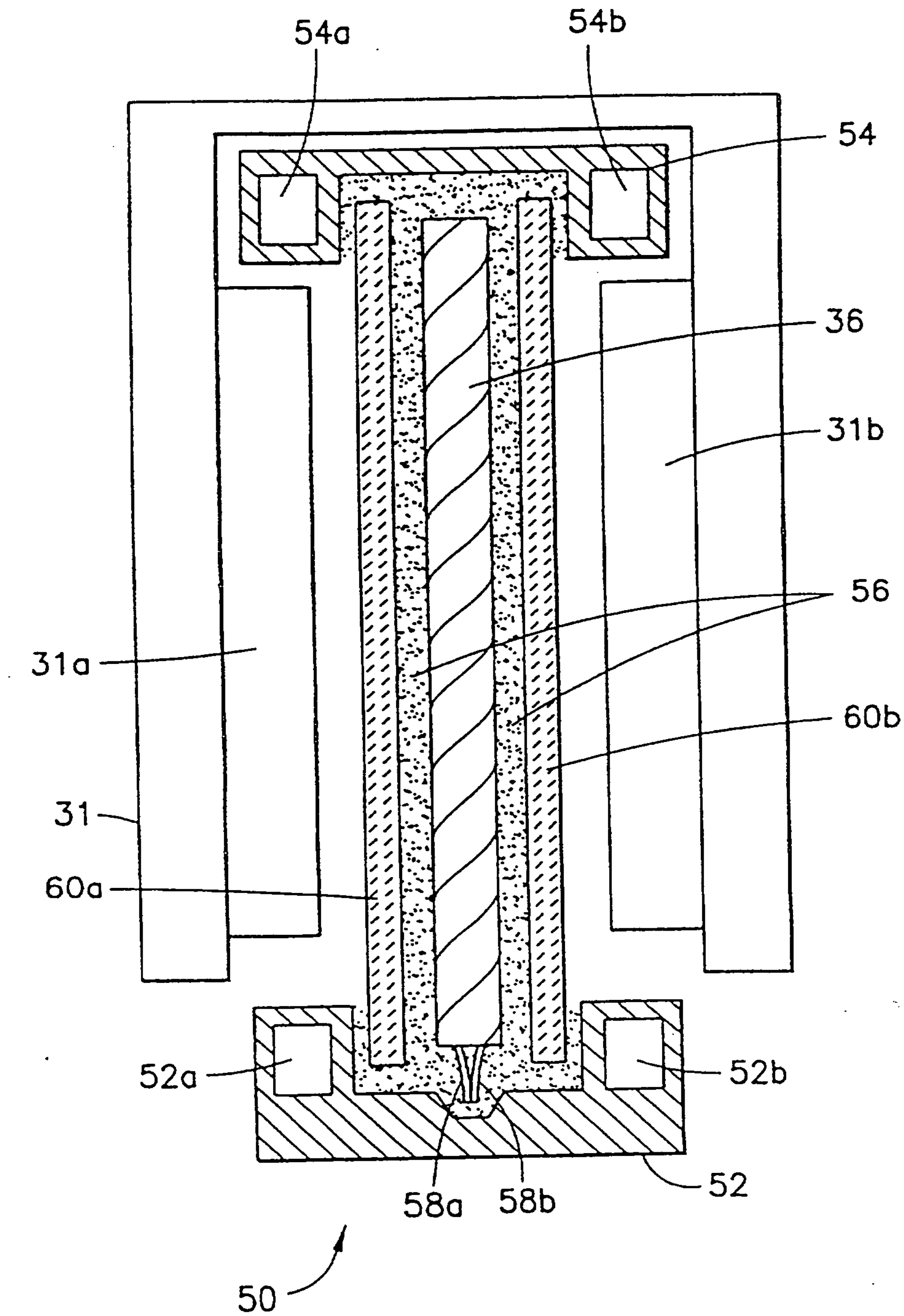

FIG.5

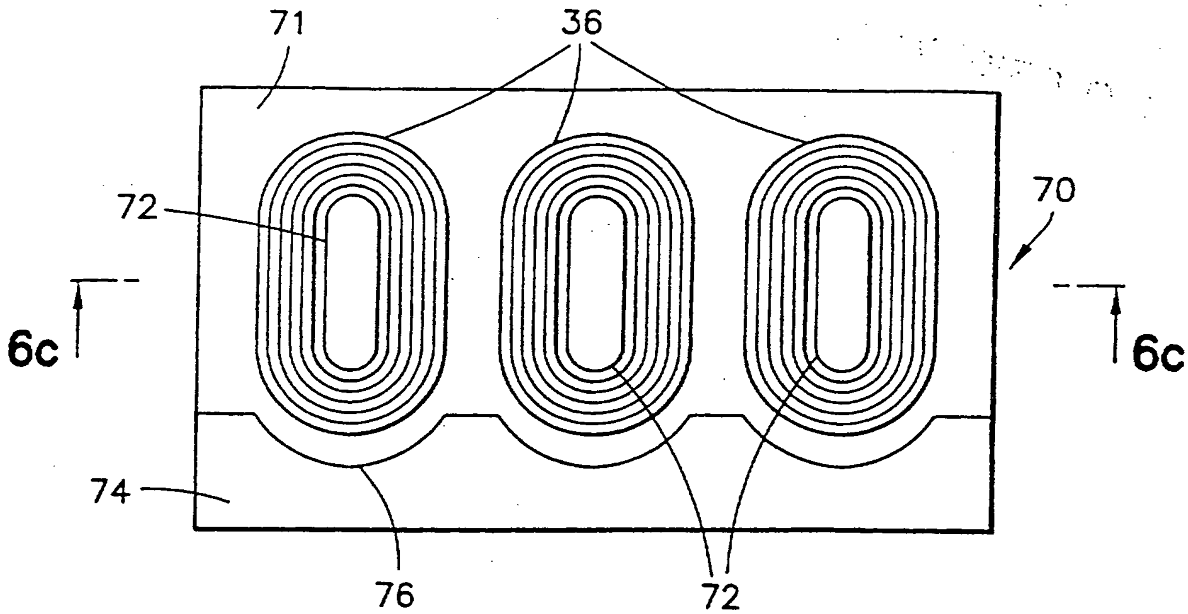

FIG.6a

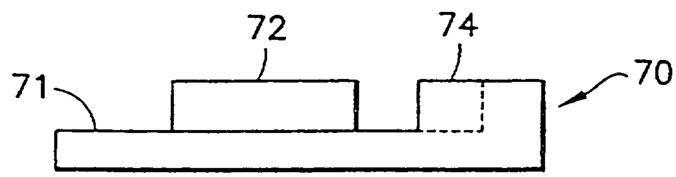

FIG.6b

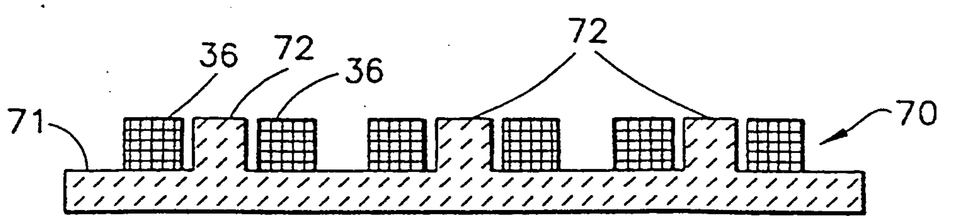

FIG.6c

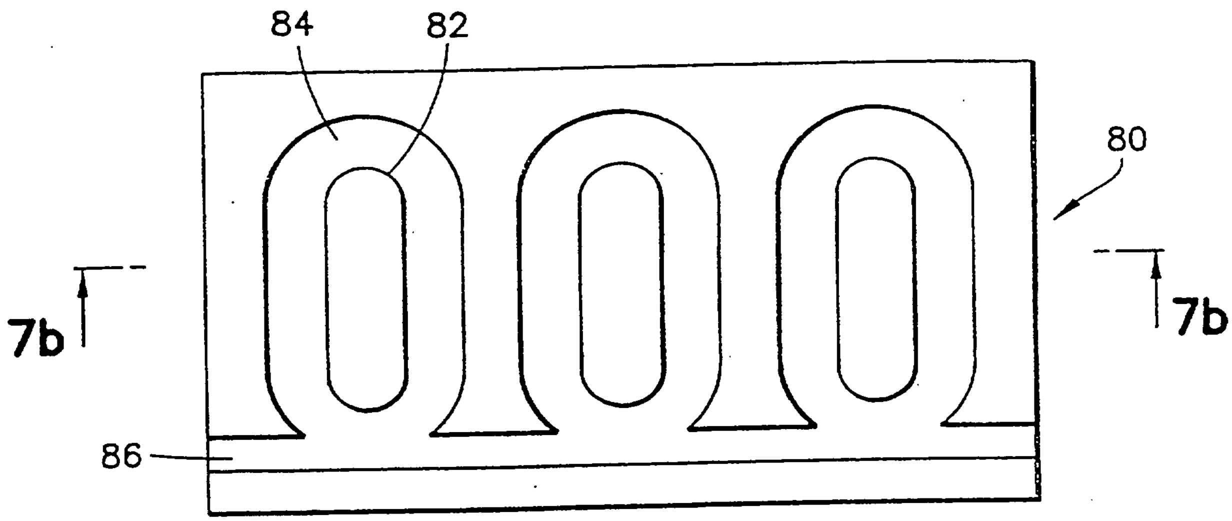

FIG.7a

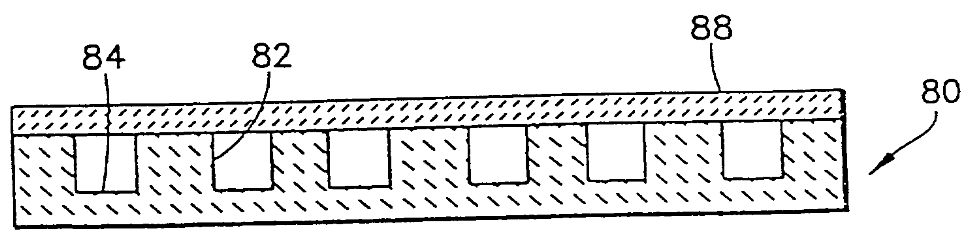

FIG.7b

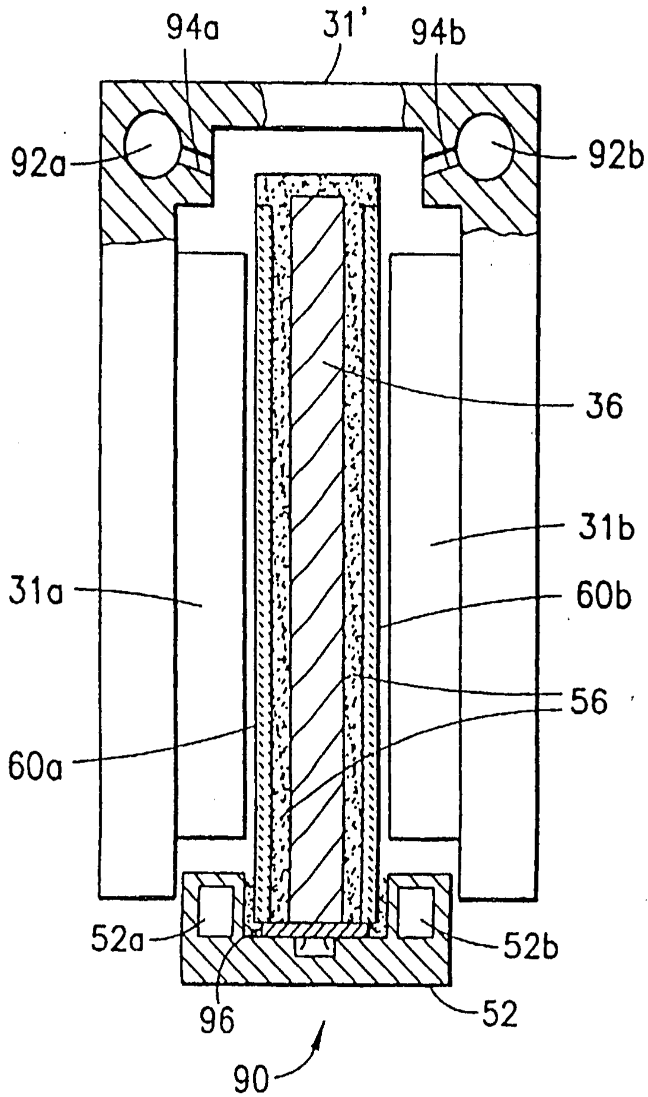
94a
31'
94b
92a
92b
36
31b
31a
60b
56
60a
52a
52b
96
52
90

FIG.8

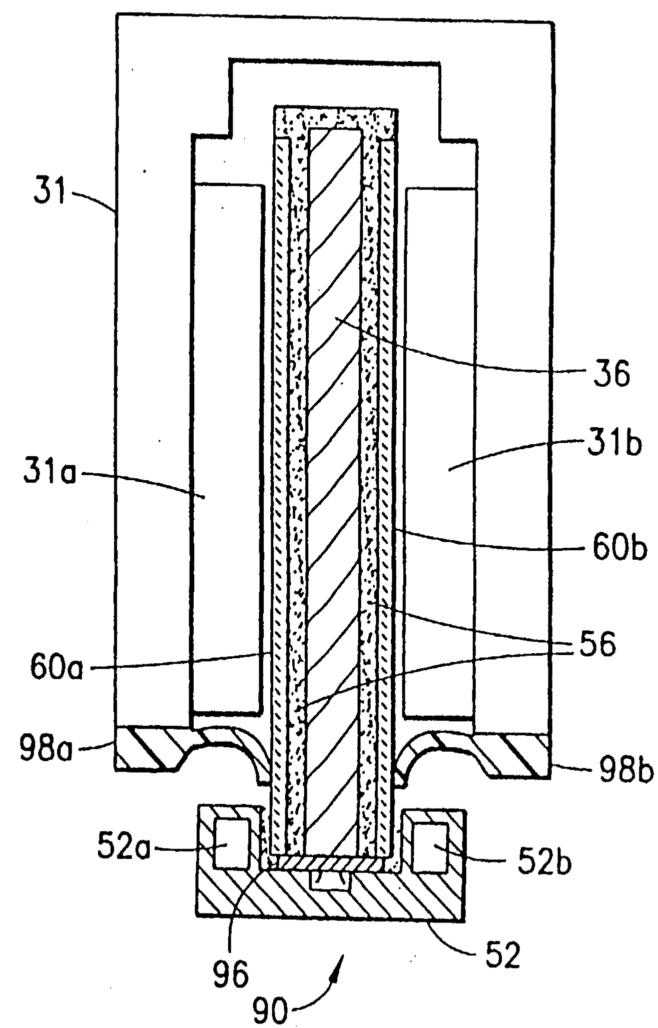
31
36
31b
31a
60b
56
60a
98a
98b
52a
52b
96
52
90

FIG.9

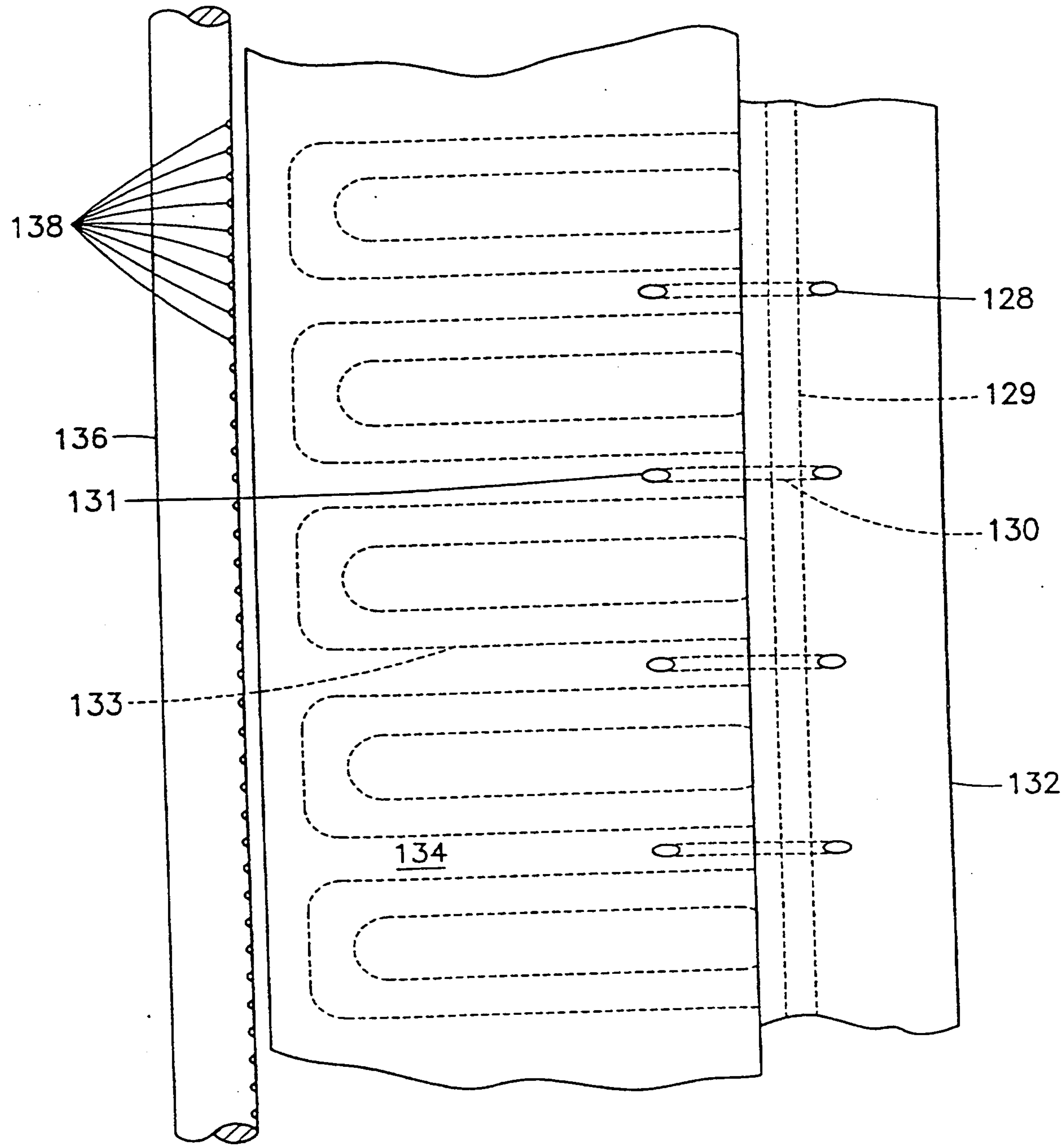

FIG. 10

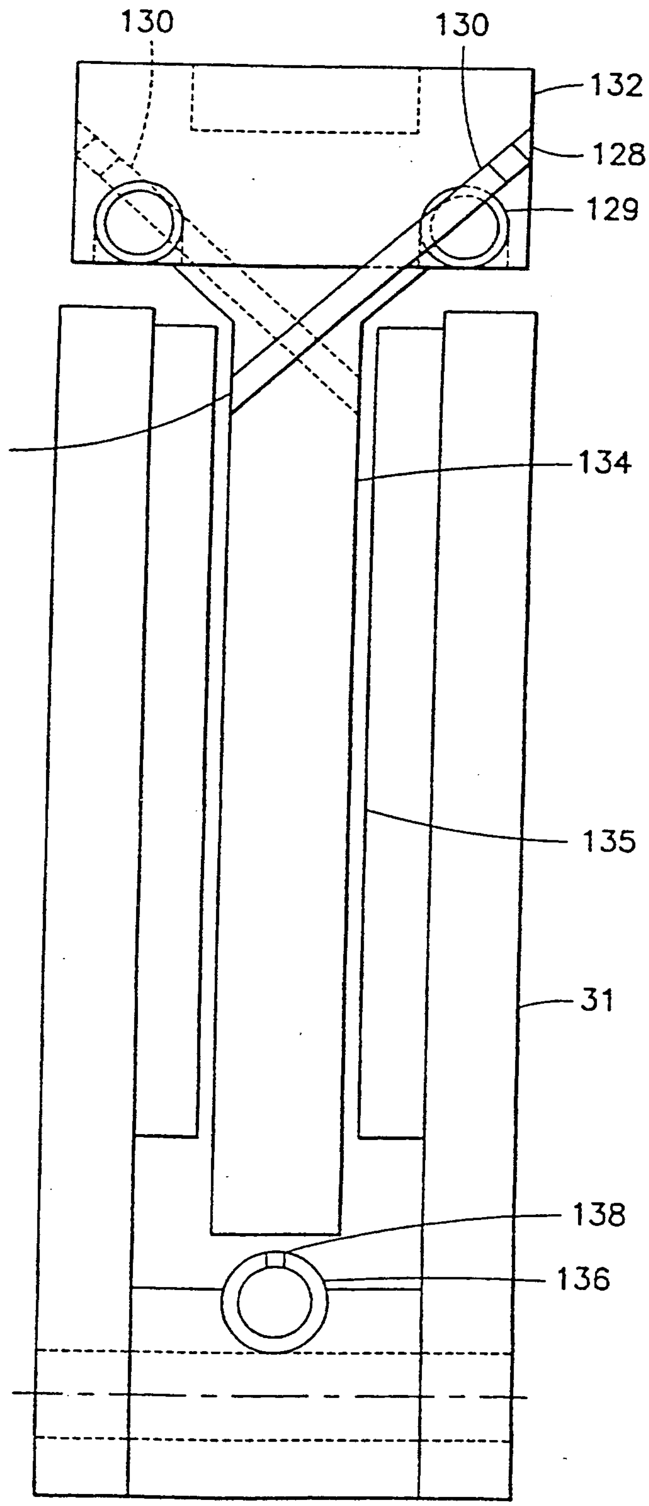

FIG.11

A LINEAR MOTOR WITH IMPROVED COOLING

The present invention relates to a linear motor with improved cooling and, more particularly, to a linear motor having cold plates on both the top and bottom of a non-magnetic armature employing ceramic materials for improved heat conduction.

Linear motors having cold plates mounted on one edge of an armature are known in the art. Also known are armatures having cooling coils or channel therein. Examples of such armatures are disclosed in U.S. Paent 4,839,545. These armatures are comprised of laminates of magnetic materials.

Linear motors having non-magnetic armature are also known, an example of which is disclosed in U.S. patent 4,749,921. The linear motor of the referenced disclosure has a non-magnetic armature which includes a coil support structure composed of an aluminium frame or a serpentine cooling coil. In the embodiment having an aluminium frame, heat is carried away from coils of the armature via the aluminium frame and a side plate affixed to a first edge of the armature. Such an arrangement has a disadvantage in that heat builds up at a second edge of the armature furthest from the side plate which functions as a heat sink. Alternatively, the serpentine coil may be employed to effect more uniform cooling. The serpentine coil supports the overlapping coils while the coils and the armature are cast in a block of settable resin. However, the incorporation of such a coil has the disadvantage of increasing costs because of the complexity of assembly and material expenses. Furthermore, while the use of the settable resin prevents the occurrence of eddy currents, the thermal

conductivity of the settable resin is significantly less than that of metals which it replaces and thus reduces the power dissipation capacity of the linear motor.

Linear motors are increasingly being employed in manufacturing equipment. In such equipment, nominal increases in the speed of operation translate into significant savings in the cost of production. Therefore, it is particularly desirable to produce as much force and acceleration as possible in a given linear motor. An increase in force generated requires either an increase in magnetic field intensity or an increase in current applied to coils of the armature. Power dissipated in the coils increases at a rate equal the square of the current. Attendant heat generation severely limits the acceleration that may be achieved because of a danger of coil-overheating. Therefore, improvements in the power dissipation capacity of linear motors provide for increases in their utility.

According to the present invention there is provided a linear motor comprising a magnet member having a plurality of magnets affixed thereto in a pattern of alternating polarity and an armature member having at least one coil embedded therein in an encapsulating resin, the armature member being driven linearly along the magnet member as an electric current is applied at least one coil, wherein the armature member contains substantially no magnetic material and comprises:

a ceramic support member for said at least one coil the said ceramic member having a recessed surface which accommodates the said at least one coil set into at least one recess therein;

the ceramic member and the said at least one coil being encapsulated in said

resin; and

a heat sink in direct thermal contact with the ceramic member to dissipate the heat generated by said at least one coil and conducted to the heat sink by the ceramic support member.

In a preferred embodiment the coil or coils each have a central opening and the recessed surface of the ceramic support member is formed with one or more upstanding lands so that when the coil or coils are mounted on the surface, the lands extend through the openings in the coils so that the surface of the lands are substantially flush with the surface of the coil.

Preferably, each coil is accommodated within a respective annular recess formed in the ceramic support member. In this way individual lands extend through the openings in the coils to a level substantially flush with the surface of the coil or coils and the other lands which extend at the same level externally around and or between the coils.

In preferred embodiments the linear motor further comprises a second ceramic member superimposed as a cover over the coil or coils mounted on the recessed ceramic member.

Further preferably the ceramic support member and cover member are of silicon carbide or aluminium nitride material.

The support member may be positioned at the junction between the ceramic support member and the heat sink where the support member has a region of increased thickness to decrease the thermal resistance between the ceramic support member and the heat sink.

The heat sink may comprise either a cold plate fixed to either the top or bottom edge of the armature member or alternatively may comprise two separate plates fixed to both the bottom and top edges or the armature member.

In a preferred embodiment the cooling plate or plates are provided with cooling tubes for the flow of cooling fluid to assist in the dissipation of heat generated by the coils.

Conveniently the armature member is mounted to run within a U-shape frame having side plates to which the magnets are fixed in a proposed relationship to the armature member.

This application is a divisional application of patent application No. GB 9707524.6 which concerns a linear motor comprising a magnet member having a plurality of magnets affixed thereto in a pattern of alternating polarity and an armature member having at least one coil embedded in an encapsulating resin, the armature member being driven linearly along the magnet member as an electric current is applied to the said at least one coil, wherein the armature member contains substantially no magnetic material and comprises:

a first cooling member affixed to a bottom portion of the armature member;

a second cooling member affixed to a top portion of the armature member: and conduit means for conveying a cooling liquid to the first and second cooling members to dissipate heat generated in the armature members by the at least one coil as the electric current is applied thereto.

Another divisional application from application No. GB 9707524.6 concerns a linear motor comprising:

an elongate frame defining an elongate open channel having a U-shape cross-section formed by side walls and a cross member;

a plurality of magnets mounted on the inwardly facing walls of the channel and forming an array of magnets of opposite polarity spaced along the length of the channel;

an armature member containing substantially no magnetic material mounted for longitudinal travel in the U-frame, said armature member having an elongate coil support member positioned between the side walls of the frame and to which is mounted at least one coil to which an electric current can be supplied to cause the armature member to travel along the length of the channel, said support member and the said at least one coil being encapsulated in an encapsulating resin; and

an air duct located in the cross member of the frame and extending longitudinally therein and a plurality of orifices spaced along the channel, said orifices communicating between the air duct and the channel for either venting cooling air flowing over said inwardly facing walls of the channel in a direction towards the cross member and into the said air duct, wherein the said duct serves as an extraction duct, or alternatively for introducing cooling air fed to said duct into the channel so as to

flow over said inwardly facing walls in a direction away from said cross member.

Various embodiments of the invention will now be more particularly described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a simplified side view of an armature having single cold plate cooling of the prior art.

Figure 2a is a perspective view of a serpentine cooling tube structure of an embodiment of an armature of the prior art.

Figure 2b is a cross section view, after potting, of the armature shown in Figure 2a taken along line IIa-IIb.

Figure 3a is a partial cross section end view of a linear motor of the present invention incorporating dual cold plate cooling.

Figure 3b is an end view of the embodiment of the present invention shown in Figure 3a showing cross-over connecting tubes.

Figure 3c is a bottom view of the embodiment of the present invention shown in Figure 3a detailing the cross-over tubes.

Figure 4 presents simplified end views of three armatures, two of the prior art and one of the present invention, showing locations of temperature measurements taken on the armatures.

Figure 5 is a partial cross section end view of another embodiment of an armature of the present invention.

Figure 6a is a side plan view of yet another embodiment of the present invention having a first ceramic substrate configuration.

Figure 6b is an end view of the ceramic substrate of Figure 6a.

Figure 6c is a cross section bottom view of the embodiment shown in Figure 6a.

Figure 7a is a side plan view of still another embodiment of the present invention showing a second ceramic substrate configuration.

Figure 7b is a cross section bottom view of the embodiment shown in Figure 7a.

Figure 8 is a partial cross section end view of a further embodiment of the present invention having ducted air and cold plate cooling.

Figure 9 is a partial cross section end view of a still further embodiment of the present invention having air cooling and cold plate cooling.

Figures 10 and 11 are partial section views of another embodiment of the invention.

Referring to Figure 1, there is shown a side view of an armature assembly of the prior art having a single sided liquid cooling system. An armature 10 is mounted in contact with a cold plate 12. Heat is drawn from the armature 10 into the cold plate 12, however, since the top portion of the armature 10 is furthest from the cold plate 12 it has a path of greater thermal resistance to the cold plate 12 than does a bottom portion of the armature 10 which is close to the cold plate 12. Therefore, heat is transferred inefficiently from the top of the armature 10. Inefficient heat transfer corresponds to higher equilibrium temperatures for a given power dissipation rate. Because the materials and construction have limited ability to cope with high temperatures, the total power dissipation capacity of the armature assembly is limited by the inefficient heat transfer.

Referring to Figure 2a, an alternative cooling method, used in a non-magnetic armature of the prior art, incorporates an armature frame 14 composed of a serpentine cooling tube 16. Overlapping coils are laid upon the armature frame 14 as indicated by a dashed coil outline 18. Once each coil has been positioned upon the armature frame 14, the entire assembly is potted in resin. In Figure 2b a cross section of a potted armature assembly of Figure 2a is shown. Coils 20 have the serpentine cooling tube 14 positioned between each adjacent coil and a casing 24 of resin provides structural integrity and thermally conductive medium for transferring heat from the coils 20 to the serpentine cooling tube 14. While this construction is effective in eliminating heat from the armature, assembly is complex and the use of overlapping coils adds bulk to the structure.

Referring to Figure 3a, an embodiment of the present invention includes a non-magnetic armature 30 having a base cold plate 32 and a top cold plate 34. The non-magnetic armature 30 travels within a U-frame 31 of a linear motor and is carried and retained by a user-supplied slide means (not shown) adapted to a particular user application. The U-frame 31 supports a first and a second array of magnets of which two magnets, 31a and 31b are shown. Flat coils, of which a coil 35 is shown, are potted in an armature block 38 formed of a settable resin. The base cold plate 32 and the top cold plate 34 are affixed to a top and a bottom of the armature block 38 by means of the settable resin used to form the armature block 38. The base and top cold plates 32 and 34, have coolant tubes 40a, 40b, 40c and 40d, affixed therein. The settable resin is selected so as to provide high thermal conductivity. One such settable

resin is an epoxy resin sold by Emerson and Cumming, Inc of Canton, Mass under the trademark "SYTCAST 2850MT" which has a thermal conductivity of 20 BTU/in/hr/ft^2/Deg.F.

The flat coils of the armature block 38 are cooled by means of a liquid coolant passing through the coolant tubes 40a, 40b, 40c and 40d, in the base and top cold plates, 32 and 34. This configuration allows heat to be removed from a middle portion of the armature block by means of thermal paths to both cold plates, 32 and 34. Thus, the thermal resistance between the portion of the armature block furthest from a cold plate is half that of the single cold plate armature of the prior art. Thus, to a first approximation, the heat sinking capacity is double that of the prior art.

Furthermore, the flat coils are wound using wire of a rectangular of a square cross-section to eliminate the air gaps found in motor coils of the prior art wound from round wire. The elimination of air gaps decreases the thermal resistance from inner windings to outer windings of the flat coils. Therefore, the cooling characteristics of the armature 30 are further enhanced over those of the prior art single cold plate armature.

Referring to Figures 3b and 3c, end and bottom views of the armature assembly 30 show cross-over connecting tubes 40e and 40f. The cross-over connecting tubes 40e and 40f, connect coolant tube 30b to coolant tube 40c and coolant tube 40a to coolant tube 40d, respectively, at a first end of armature assembly 30. On a second end of the armature assembly a single connecting tube (not shown), similar to either of

connecting tubes 40e and 40f, connects coolant tubes 40b and 40a. Flexible tubing supplies coolant to tube 40c which feeds coolant to tube 40b via connecting tube 40f which conveys coolant to tube 40d. Coolant runs down tube 40d and out through another attached flexible tube. Thus, all tubes are fed serially while the motor is in operation.

Referring to Figure 4, end views of the armature assembly 30 and two prior art armature assemblies, 40 and 41, depict the cooling configuration of each assembly. Each armature assembly is mounted upon a mount plate 42. Armature assembly 40 has no liquid cooling, armature assembly 41 has liquid cooling via a base cold plate, and the armature assembly 30 has both base and top cold plate cooling as discussed above. Temperature monitoring locations A, B, C and D, are indicated on each armature assembly. The maximum rated temperature for the coils of the armature assemblies, 30, 40, and 41, is 120C.

To evaluate the effectiveness of the cooling configuration of armature assembly 30, power applied to each armature assembly was increased until the rated temperature was reached at some point on the given armature. Table 1 below shows the results of this test. The single cold plate armature 41 was capable of carrying 3 amps and the no-liquid-cooling armature 40 accepted 2.6 amps before each reaching the rated temperature at position D on the assemblies, which is furthest from the mount plate 42. In comparison, the dual cold plate armature assembly 30 handled 4 Amps before the rated temperature was reached at location B at the base cold plate.

A more uniform operating temperature in a given armature assembly is indicative off efficient heat removal and provides for achieving maximum utility from the armature. If a localised area of an armature limits operation due to heating, then maximum utility is not derived from the remainder of the armature which is well within the safe operating temperature region. Thus, the advantage of dual cold plate cooling is demonstrated.

TABLE 1

Location Armature	A TEMP (C)	B TEMP (C)	C TEMP (C)	D TEMP (C)	E TEMP (C)	F TEMP (C)	G TEMP (C)
30 (Double sided cooling)	39	122	114	102	4	254	0.4
40 (Single sided cooling)	38		73	120	3	138	0.9
41 (no cooling)	65		79	120	2.6	94	1.3

The translation of current capacity into power dissipation capacity provides a further measure of the improvement provided by the cooling configuration of the dual plate armature assembly 30. The power capacity of the dual cold plate armature 30 exceeds that of the single cold plate armature 41 by 84%. This represents a significant improvement in the power capacity of a linear motor, allowing for greater forces and acceleration.

Referring to Figure 5 a cross-section through another embodiment of the present invention is shown. An armature assembly 50 is similar to the above embodiment except as stated herein. A base cold plate 52 and top cold plate 54 are produced from extrusions with integral passages replacing the coolant tubes 40a, 40b, 40c and 40d, in the aforementioned embodiment. The base cold plate 52 includes coolant passages 52a and 52b. The top cold plate 54 includes coolant passages 54a and 54b. The coolant passages 52a, 52b, 54a, and 54b, are readily formed in the extrusions by methods familiar to those skilled in the art of extrusion design. Cross-over connections at ends of the coolant passages can be implemented by means realisable by those skilled in the art of manufacture and are not detail herein. Coil lead wires 58a and 58b connect to a trailing cable (not shown) via wiring or a printed circuit board in the base cold plate 52 or cast into the settable resin.

The use of extrusions in the construction of the cold plates, 52 and 54, saves time used and expenses incurred during manufacture by elimination of the need to bond the coolant tubes 40a, 40b, 40c and 40d, into the cold plates, 32 and 34, of the aforementioned embodiment. Furthermore, thermal resistance between the cooling liquid and the armature block 38 is reduced because a thermal resistance of a bonded interface between the coolant tubes 40a, 40b, 40c and 40d, and the cold plates 32 and 34 is eliminated. The lowered thermal resistance produces still further improvements in cooling efficiency.

The extrusions comprising the cold plates, 52 and 54, are formed from aluminium. Aluminium's low thermal resistance and its lightweight make it particularly suitable

to this application. However, aluminium is also electrically conductive which permits the production of eddy currents in the cold plates, 52 and 54, which travel through magnetic fields created by the magnets, 31a and 31b, of the U-shaped frame 31. Eddy currents produce drag upon the armature and dissipate energy as heat. Therefore, in applications requiring high speed, electrically non-conductive materials which have high thermal conductivities are preferred. Ceramic materials such as silicon carbide and aluminium nitride satisfy these requirements and are used in embodiments requiring these characteristics. Other such materials may be identified by those skilled in the art and are within the scope and spirit of the present invention.

Settable resin 56 is used to bond the armature assembly 50 together. This settable resin 56, as discussed above, is chosen for its high thermal conductivity. Although the thermal conductivity of the settable resin 56 is high for a resin, it is not as high as thermal conductivities of aluminium or ceramics. For example, resin core motors exhibit a typical thermal conductivity of 1 W/C-m while motors employing steel laminations have a typical thermal conductivity of 30 W/C-m. In order to improve the thermal conductivity of the armature assembly 50, heat sink plates, 60a and 60b, serve to further decrease the thermal resistance between a middle portion for the armature assembly 50 and the base and top cold plates, 52 and 54, because the heat sink plates, 60a and 60b, have a thermal conductivity superior to that of the settable epoxy resin.

The heat sink plates, 60a and 60b, are formed of electrically non-conductive and non-magnetic but thermally conductive materials such as the aforementioned ceramics.

The components are assembled together into the armature assembly 50 using the epoxy resin described in the embodiment shown in Figure 2. The use of ceramic type materials results in the armature assembly 50 being non-magnetic, and non conductive with the exception of the coils 36, thereby effectively eliminating eddy currents which cause drag and heating of the armature assemblies while improving the thermal conductivity of the armature assembly 50. While the heat sinks plates, 60a and 60b, are shown functioning in conjunction with the base and top cold plates, 52 and 54, other embodiments of the present invention may employ such heat sink plates functioning with a single cold plate or a heat sink member employing fins or other means to dissipate heat aside from liquid cooling.

Referring to Figures 6a, 6b and 6c, a further embodiment of the present invention is shown wherein a ceramic substrate 70 has the coils 36 (not shown in Figure 6b) mounted upon it. The ceramic substrate 70 has a recessed surface 71 from which raised islands 72 extend into openings of the coils 36. A base portion 74 has contours 76 in which lower portions of the coils 36 extend. The ceramic substrate 70 is potted with settable resin and a cold plate (not shown) of one of the above embodiments is affixed to the base portion 74. The islands 72 and contours 76 are dimensioned so as to provide a close fit with the coils 36, minimising the amount of settable resin between the coil 36 and the ceramic substrate 70 and thus, also minimising the thermal junction resistance. The islands 72 draw heat away from the centre of the coils 36 by providing a low thermal resistance path to the base portion 74 and a cold plate (not shown) attached thereto. The thicker base portion 74 increases the surface area through which heat flows from the ceramic substrate 70 into the cold plate,

reducing the thermal resistance of the junction between the cold plate and the ceramic substrate. Once again, the superior thermal conductivity of the ceramic substrate 70 provides for a significant cooling improvement over an armature assembly constructed using only resin encapsulation. Additionally, a ceramic cover plate (not shown) may be affixed over the ceramic substrate 70 thereby further increasing the thermal conductivity to the cold plate. Another embodiment has a second cold plate affixed to the top of the ceramic substrate 70 to further enhance cooling.

Referring to Figures 7a and 7b, another embodiment of the present invention is shown wherein a ceramic substrate 80 has annular recesses 84 forming islands 82. The annular recesses 84 are dimensioned to provide for a close fit with coils (not shown) inserted into the annular recesses 84. A trough 86 is provided to accept coil leads connected to a control cable (not shown). Coils are inserted in to the annular recesses and potted therein using high thermal conductivity settable resin. A ceramic cover plate 88, shown in Figure 7b, is optionally affixed over the ceramic substrate, further improving thermal conductivity of the ceramic substrate assembly. Cold plates (not shown) are affixed to top and base portions of the ceramic substrate assembly in a similar manner as that shown in the above embodiments. The high volumetric content of ceramic material in such an armature assembly serves to provide superior thermal characteristics without the use of electrically conductive or magnetic materials which produce eddy current drag and losses.

Referring to Figure 8 another embodiment of the present invention is shown including air cooling. An armature assembly 90 is similar to the armature assembly 50 of

Figure 5 except as provided herein. The armature assembly 90 is provided with a single cold plate, the base cold plate 52. The use of the base cold plate 52 alone allows the armature assembly 90 to be extracted in a downward vertical direction anywhere along U-frame 31. Although base cold plate 52 is shown composed of an extrusion, it is realised that a cold plate of proper size using other construction techniques may be employed.

The U-frame 31 includes air passages, 92a and 92b, which provide a flow of cooling air via orifices, 94a and 94b, to a space surrounding a top of armature assembly 90. The flow of cooling air removes heat from the top portion of the armature assembly 90 which is furthest from the base cold plate 52. This provides for more uniform cooling than is achieved if only the base cold plate 52 was employed. Therefore, the armature assembly may operate at higher power levels than similar non-magnetic armatures of the prior art.

The base cold plate 52 further includes a printed circuit board 96 into which leads from the coils 36 connect. A trailing cable (not shown) is then connected to the printed circuit board. Other means of wiring, including harnesses and flexible printed cirucits connected to the trailing cable and coil leads, may be incorporated into the base cold plate 52 or cast in the resin encapsulation. Such methods are included within the scope and spirit of the present invention.

Referring to Figure 9, still another embodiment of the present invention employing air cooling is shown. The armature assembly 90 travels in the U-frame 31. The U-

frame 31 includes seals, 98a and 98b, mounted along lower edges of the U-frame 31. The seals, 98a and 98b, are formed of a flexible plastic or rubber material and extend along the entire length of the U-frame 31. Along portions of the U-frame where the armature assembly 90 is not present, the seals, 98a and 98b, engage each other preventing the escape of air from the U-frame. A flow of cooling air is introduced into a first end of the U-frame 31 and exits by a second end of the U-frame 31. Adaptors (not shown) on the first and second ends of the U-frame 31 interface with means of supplying cooled air and are readily realisable by those skilled in the art. The cooling air passes over the armature assembly 90 thereby cooling it. The seals, 98a and 98b, are pushed apart by longitudinal movement of the armature assembly 90 in the U-frame 31. Due to a larger area for passage, a greater flux of flowing air exists around the top portion of the armature assembly 31 which is otherwise subject to heat build-up since it is furthest from the cold plate 52. Thus, uniform cooling of the armature assembly 90 is effected by the combination of the base cold plate 52 and the cooling air flow at the top portion of the armature assembly 31.

The embodiment of Figure 9 allows the armature assembly to be removed from the U-frame 31 at any location along its length since there is no cold plate on the top portion of the armature assembly 90 to prevent its removal. Furthermore, the seals, 98a and 98b, serve to prevent debris from entering the U-frame and interfering with operation of the linear motor. Similarly, seals may be incorporated into the embodiment presented in Figure 8. Additionally, vertical cooling fins may be added to the top portion of the armature assembly 90 to further enhance the cooling effect of the flowing air.

Referring to Figures 10 and 11, a base element 132 is provided with an air passage 129. Minor channels 130 are drilled through base element 132 to connect major channel 129 to a space 135 between armature bloc 134 and U-frame 31. The design of the embodiment of Figures 10 and 11 allows easy manufacture by drilling out minor channels 130. Entry and exit of a drill tool can be accommodated easily as can be seen by noting the positions of entry hole 128 and exit hole 131. Entry hole 128 is plugged to seal the air passages so that all the air is injected into space 135. The course followed by cooling air is as follows: Air is distributed through air passage 129 to all of the minor channels 130. Minor channels 130 inject air into space 135. Air flows through the space and is drawn out through apertures 138 into exit channel 136. Apertures 138 are distributed along the length of U-frame 31. Ideally apertures are located between exit holes 131 so air must flow diagonally across the armature. In addition, a large number of small apertures can be used to improve distribution of flow across the surface of armature plate 134. Note that air could be distributed and taken up in the opposite direction as well. That is air could be conveyed into the space between U-frame 31 and armature plate 134 and then out through exit holes 131 and duct 129.

Although according to the above embodiments, the upper and lower cooling tubes are connected in series, it is apparent from the present disclosure that each pair of tubes could be fed in parallel. In that case, since heat transfer fluid would be carried in parallel in twice as many tubes for a given section of armature block, the volume of fluid is increased over that of the prior art without increasing the tubing diameter.

This would result in lower temperature rise of the heat transfer fluid and further increasing the rate of heat transfer and the attendant power dissipation capacity.

Having described preferred embodiments of the invention with reference to the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments, and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the invention as defined in the appended claims.

CLAIMS

1. A linear motor comprising a magnet member having a plurality of magnets affixed thereto in a pattern of alternating polarity and an armature member having at least one coil embedded therein in an encapsulating resin, the armature member being driven linearly along the magnet member as an electric current is applied at least one coil, wherein the armature member contains substantially no magnetic material and comprises:

a ceramic support member for said at least one coil the said ceramic member having a recessed surface which accommodates the said at least one coil set into at least one recess therein;

the ceramic member and the said at least one coil being encapsulated in said resin; and

a heat sink in direct thermal contact with the ceramic member to dissipate the heat generated by said at least one coil and conducted to the heat sink by the ceramic support member.

2. A linear motor according to Claim 1, wherein the said at least one coil has a central opening and the recessed surface of the ceramic support member is formed with upstanding land(s), which when the at least one coil is mounted on said surface, extend through the opening(s) said at least one coil, the surface of the land(s) being substantially flush with the surface of the coil.

3. A linear motor according to Claim 2, wherein the said at least one coil is

accommodated within individual annular recess(es) in the ceramic support member, the support member thus having individual land(s) which extend through the opening(s) in the at least one coil to a level substantially flush with the surface of the coil and other land(s) extending to the same level externally around and/or between the at least one coil.

4. A linear motor according to any of Claims 1 to 3, further comprising a second ceramic member superimposed as a cover over the coil mounted on the said recessed ceramic support member.

5. A linear motor according to any of Claims 1 to 3, wherein the ceramic support member, and/or cover member are of silicon carbide or aluminium nitride.

6. A linear motor according to any preceding claims, wherein at the junction between the ceramic support member and the hear sink, the support member has a region of increased thickness thereby to decrease the thermal junction resistance between the ceramic support member and the heat sink.

7. A linear motor according to any preceding claim, wherein the heat sink comprises either a cold plate affixed either to the bottom or top edge of the armature member or two separate such plates affixed to both the bottom and top edges of the armature member.

8. A linear motor according to Claim 7, wherein the cooling plate(s) is or are

provided with cooling tubes for the through flow of a cooling fluid to assist in the dissipation of the heat generated by said at least one coil.

9. A linear motor according to any preceding claim, wherein the said armature member is mounted to run within a U-shaped frame having side plates to which the said magnets are affixed in opposed relationship to the armature member.

10. An armature for a linear motor of the type comprising a magnet member having a plurality of magnets fixed thereto in a pattern of alternating polarity and an armature member having at least one coil embedded therein in an encapsulating resin, the armature member being driven linearly along the magnetic member as an electric current is applied to the said at least one coil; wherein the armature member contains substantially no magnetic material; the armature comprising:

ceramic support member for said at least one coil the said ceramic member having a recessed surface which accommodates the said at least one coil set into at least one recess therein;

the ceramic member and the said at least one coil being encapsulated in said resin; and

a heat sink in direct thermal contact with the ceramic member to dissipate the heat generated by said at least one coil and conducted to the heat sink by the ceramic support member.

A linear motor substantially as hereinbefore described with reference to, and as shown in Figures 3 to 11 of the accompanying drawings.

An armature for a linear motor substantially as hereinbefore described with reference to, and as shown in Figures 3 to 11 of the accompanying drawings.

24

Application No: GB 0026032.3
Claims searched: 1 to 10

Examiner: John Donaldson
Date of search: 9 November 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): H2A(ARD4, ARK3)

Int Cl (Ed.7): H02K 3/24, 9/22, 9/24, 41/03

Other: Online:WPI, CLAIMS, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB 1434151 (AEG), see Figure 1	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		